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EVALUATION OF MODIFIED BORE EROSION GAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A bore erosion gage developed earlier (Krupski and Audino, WVT QA-7701 (1977)) for monitoring the coating thickness and erosion of the 105 mm M68 in the region up to 40 inches from the origin of rifling has been modified, and the problem of the lack of responsibility of radius measurements along the bore circumference has been successfully eliminated. Test data and statistical analysis of the results have demonstrated that the modified gage can measure

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20. ABSTRACT (CONT'D)

the relative change in the bore radius with an accuracy of ± 0.005 inch. The statistical accuracy can be further improved by increasing the number of data points.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLES

ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical assistance contributed by Mr. Fortune J. Audino, Mr. Dave Sofranko, and Mr. Paul Croteau.

INTRODUCTION

Bore erosion is one of the major problems of advanced Army Gun Barrels, and indeed it is one of the thrust areas under investigation in DARCOM. One of the immediate areas of concern is the secondary wear in the 105 mm M68. Currently in an effort to control wear in guns numerous protective coatings are being evaluated as an immediate solution to the secondary wear problem.

To ascertain the uniformity of the thickness and concentricity of coatings as well as the non-uniform circumferential erosion of gun tubes, a precision bore measuring gage became necessary. Under an MTT project entitled, "Measurement of Bore Erosion"[1] a gage was developed by Watervliet Arsenal's Gage Section which provided circumferential profiles up to 40 inches from the origin of rifling of the bore with high sensitivity. The gage which measured the radius of the bore from an established centerline provided the required data, except that the gage, upon disengagement and remounting did not yield reproducible results.

The object of this effort was:

a. To modify the centering stage of the gage in order to make it insensitive to positioning errors and thus rugged for field tests.

b. To provide documentation as well as test results representing the enhanced reproducibility attained based on statistical analysis of the data.

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[1] S. J. Krupski and F. J. Audino, "Measurement of Bore Erosion," WTV-QA-7701, December 1977.

DESCRIPTION OF DESIGN MODIFICATION

Reference 1 describes in detail the erosion gage shown in Figure 1. Prior to the modification, alignment of the gage was accomplished by means of four slit pads spaced 90° apart which were positioned at the rear of the gage assembly as shown in Figure 2. This provision allowed for a fine adjustment of up to 0.020 inch of radial displacement in positioning the rear of the assembly in order to achieve coincidence between the center line of the gage and the axis of the bore.

The modification of the gage described here and shown in Figures 3 and 4 is based on the requirement that the instrument record reproducible circumferential profiles of the gun bore. This was accomplished by replacing the adjustable but very sensitive rear positioning mechanism of the gage with a more rugged fixed unit that remains stable during successive engagements to the tube.

The modification shown in Figure 4 consists of a centering ring, tapered on the outside diameter to coincide with the powder chamber taper of the tube, and a straight bore bearing surface which slides on the rear bearing surface of the gage during the centering operation. Also shown in Figure 4 is a set of knurled headed toggle screws. The screws are mounted on the face of the ring and serve to release the tapered centering ring during disengagement of the gage from the tube.

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[1] S. J. Krupski and F. J. Audino, "Measurement of Bore Erosion," WTV-QA-7701, December 1977.

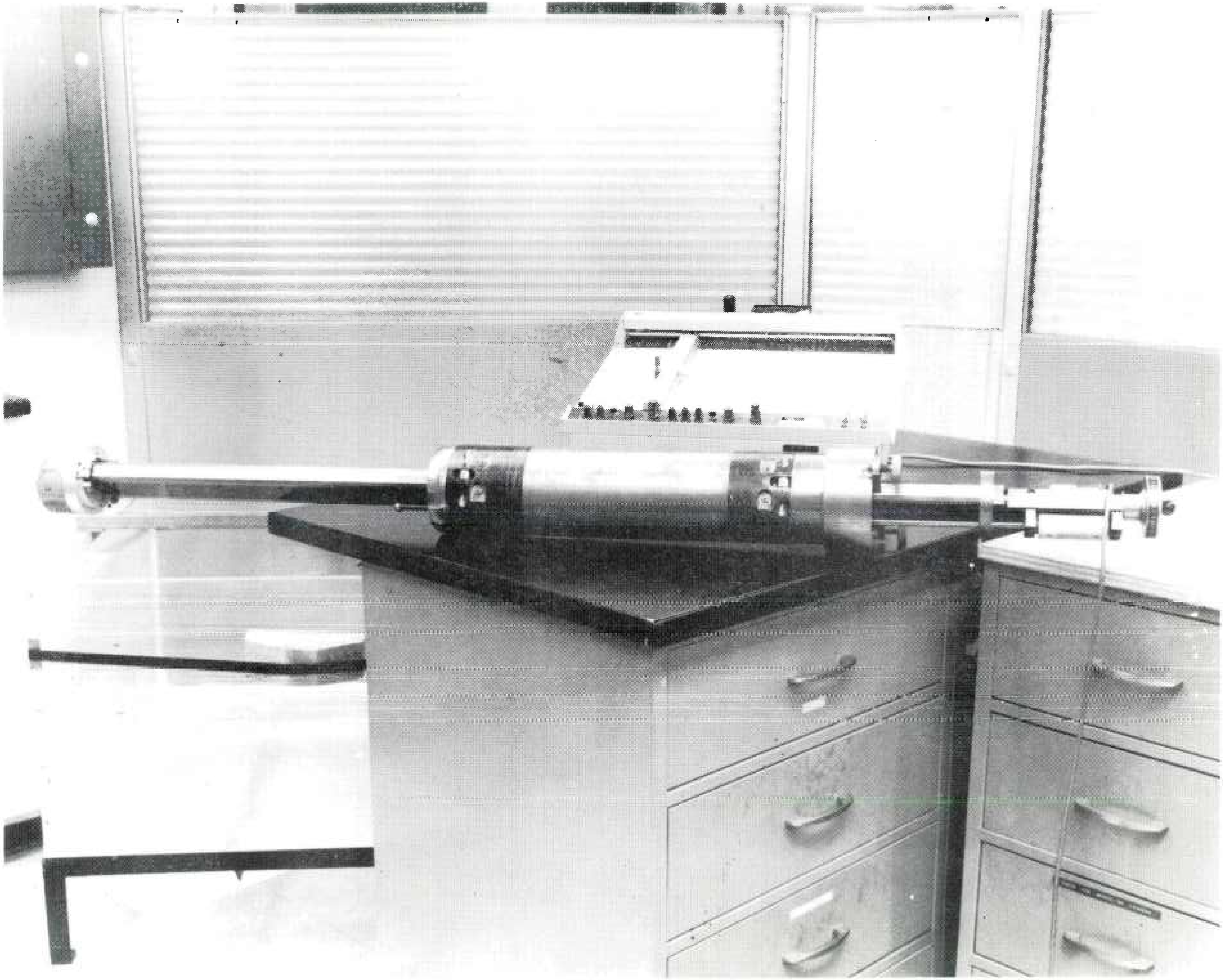

Figure 1. Bore erosion measuring system.

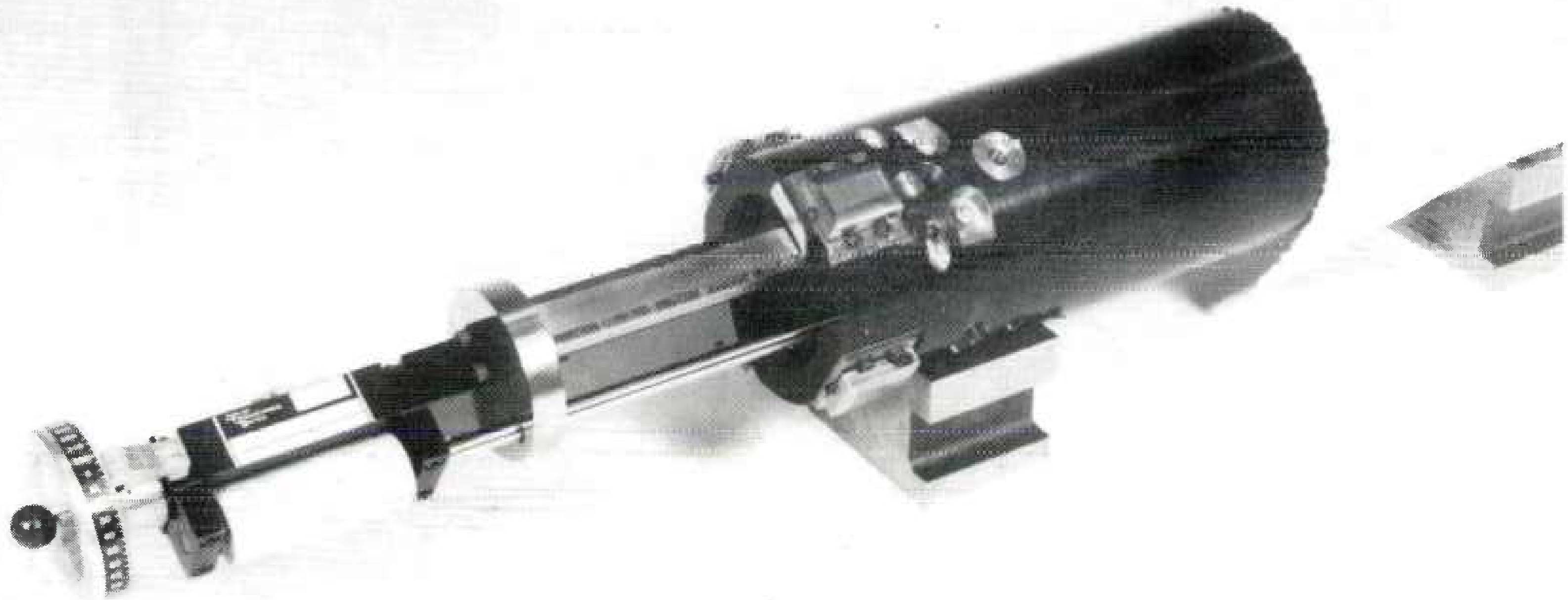

Figure 2. Rear alignment mechanisms prior to modification.

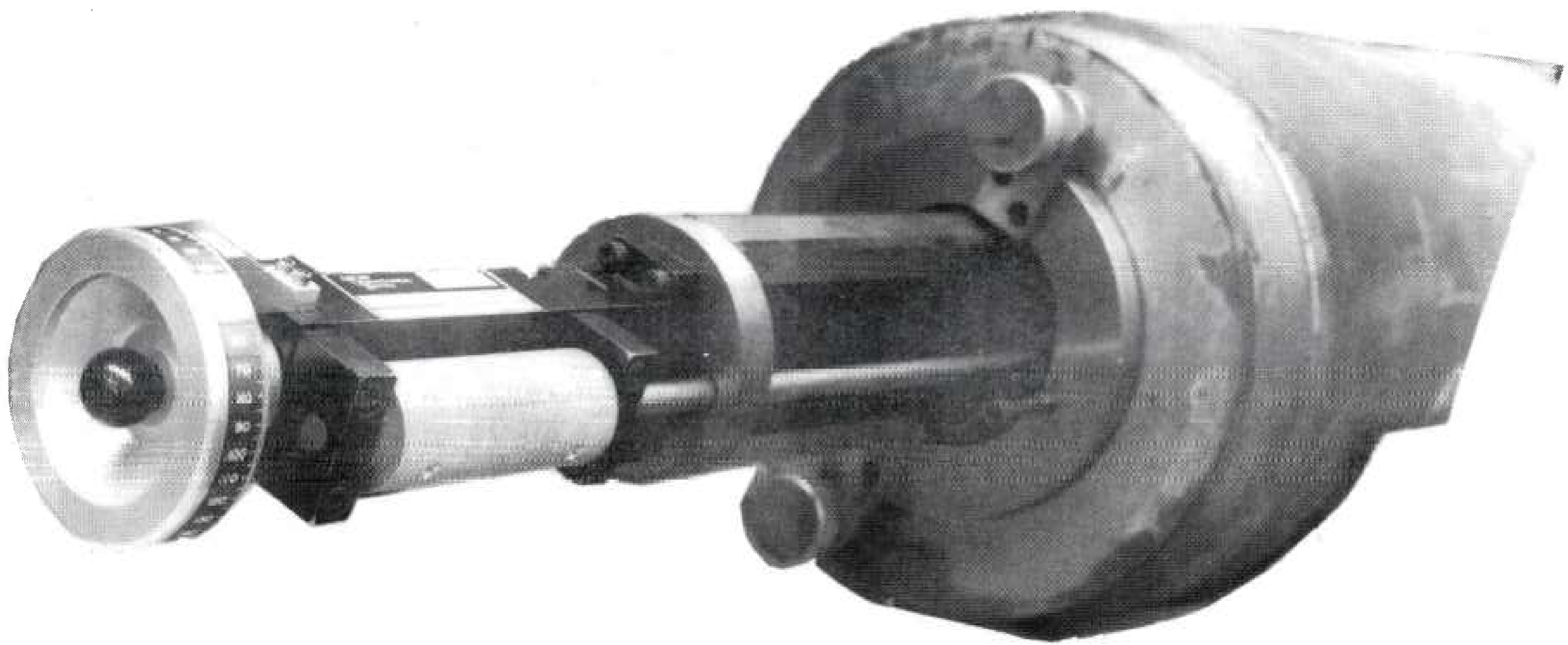

Figure 3. View of modified centering mechanism.

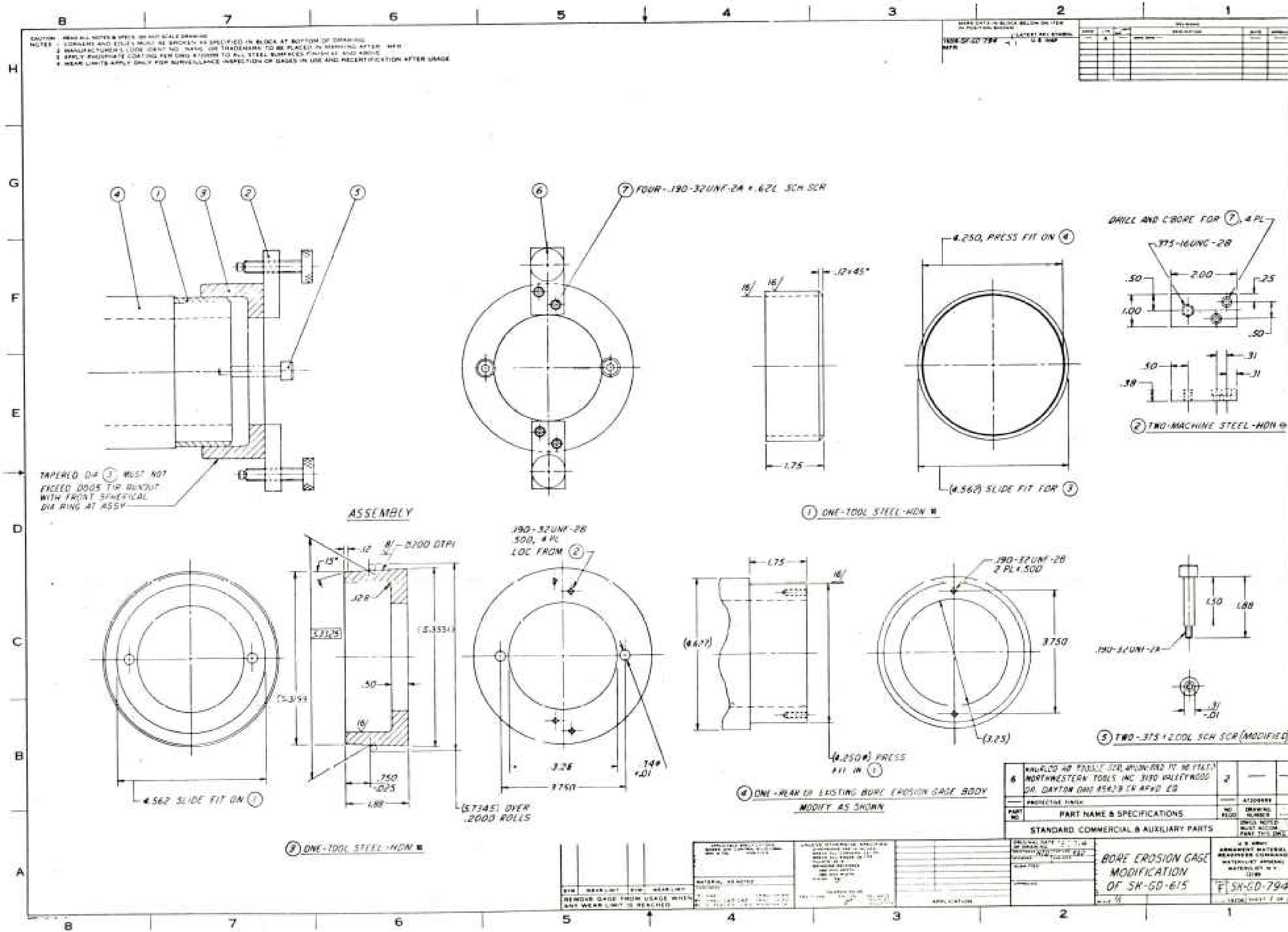

Figure 4. Detail description of modification assembly.

EXPERIMENTAL APPROACH

Two sets of data were taken for the evaluation of the modified bore erosion gage. The first set was taken from a non-eroded gun tube stub. This data was used to determine the reproducibility of the gage readings. The second set of data was taken from a worn tube stub, prior to, and after successive electropolishing steps which effectively enlarged its bore diameter.

CALIBRATION

Preceding any test, calibration was accomplished by means of a precision block. This block when placed over the extended sensor pin of the gage, locates an arbitrary zero for the y-axis. The pin is then shifted on a precision machined 0.050 inch step of the calibration block, and the y-axis range is adjusted to be 5 inches over the zero line. Thus the y-axis represents 0.010 inch per chart inch or 1 mil of bore radius change per division (0.1 inch) change of the y-axis. The x-axis represents the circular travel of the pin within the tube and is calibrated to be 360° full scale. Both axes are shown in Figure 5.

PROCEDURE

Twelve circumferential profile runs were taken from the non-eroded tube over the course of several days under varying equipment warm-up periods. Prior to each run the gage was removed from the tube and reseated. Benchmarks were established in order to reseat the gage in the same position relative to the tube. All runs were taken at the two inch mark on the gage's z-axis. It should be noted that this point represents the full extension of the gage, and errors due to gage misalignment are most pronounced at this point.

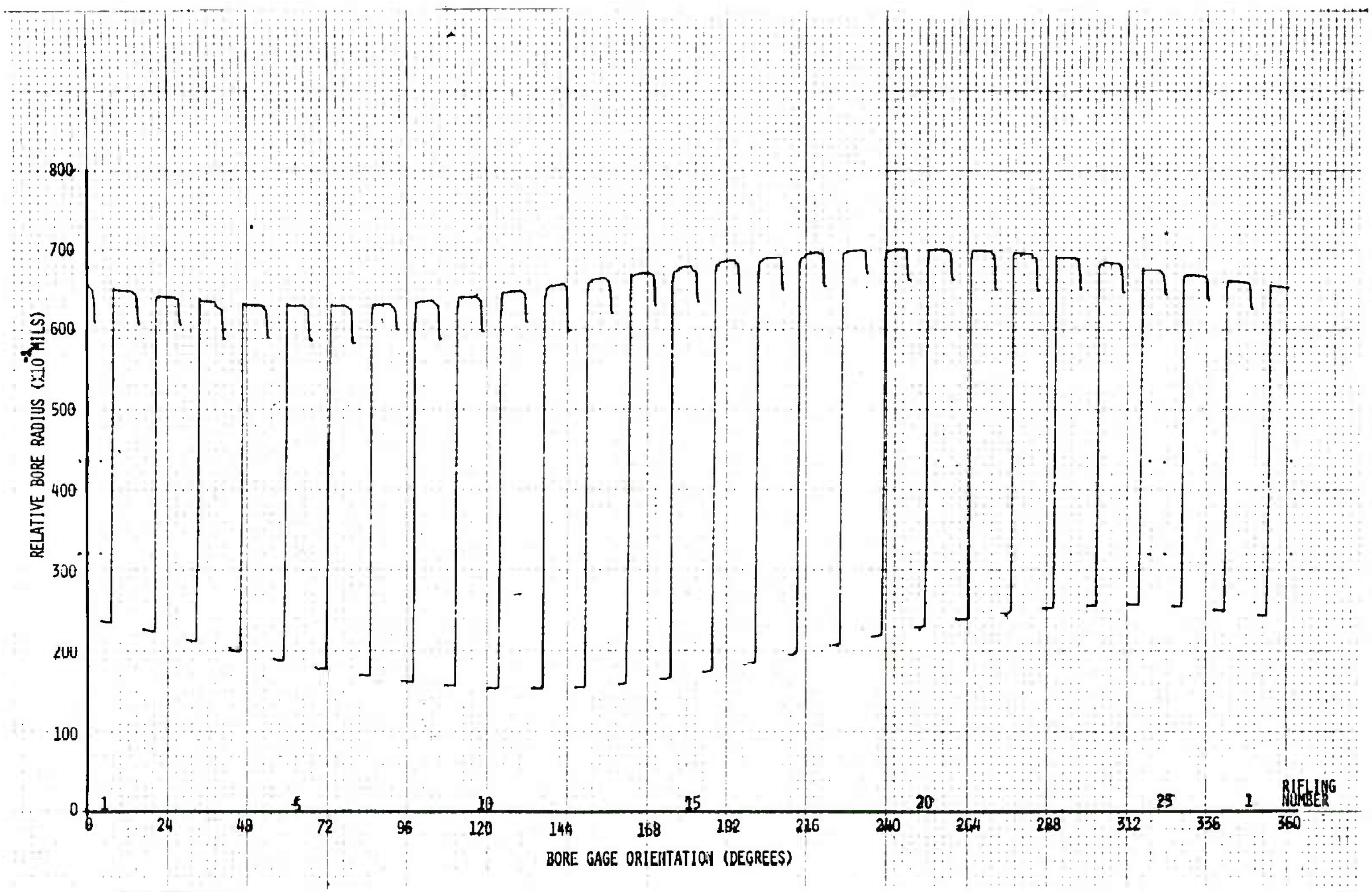

Figure 5. Expanded view of plotted data.

Each profile run contains a representation of the bore radius on each of the 28 riflings around the 360° circumference of the bore. Two data points were taken from each rifling; relative land distance and relative groove distance. Tables I and II show both measurements expressed in ten thousands of an inch with respect to an arbitrary zero line established during calibration.

In the second test, the gage was used to evaluate the extent of removal of material inside a worn tube stub due to successive electropolishing intervals. Prior to electropolishing, a calibration was performed and benchmarks were established. Ten runs were obtained at the nine inch setting of the z-axis. Two data points (land and groove radial distance) were taken for each rifling. The tube was electropolished for one hour and three profile runs were recorded. The tube was electropolished a second time for two hours and five profiles were recorded.

ANALYSIS AND DISCUSSION OF RESULTS

Figure 6 is a typical profile indicating a non-uniform radial distance along the 360° bore sweep. This is either due to the test item being out of round or because the gage does not seat in the center of the tube. Further investigation indicated that both factors contributed to the effect. Since the inner diameter tolerance specification is 2-4 mils and the deviation indicated by the data was 12 mils, it is concluded that the remaining error is due to the gage being misaligned with respect to the axis of the tube. It is this misalignment that prevents accurate measurements of the bore radius on an absolute scale. Given a precision machined tube, the gage axis could be adjusted by means of a laborious trial and error approach, thus enabling

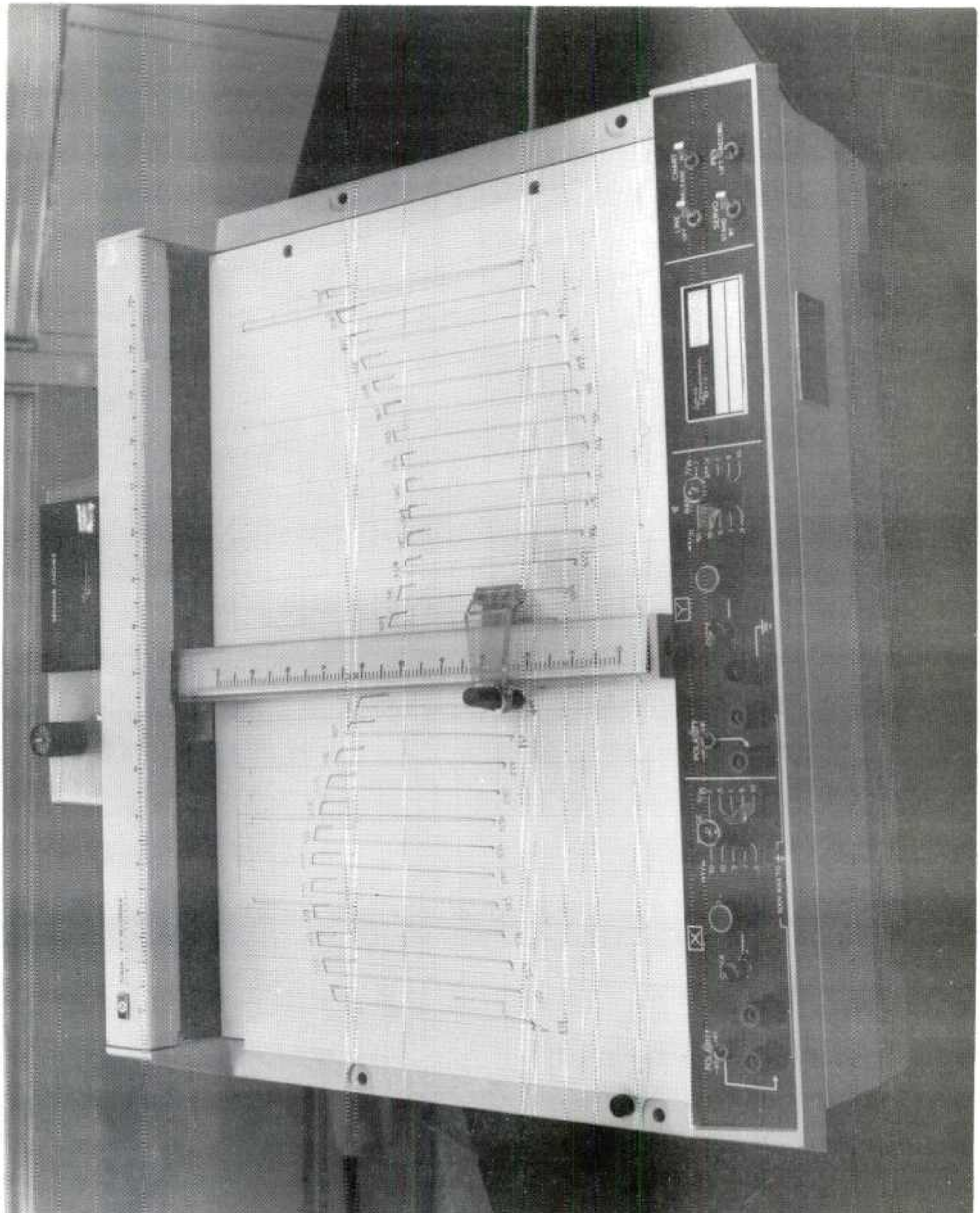

Figure 6. Typical circumferential profile plot.

absolute measurements to be made in this instance. However, since such a time consuming calibration could not be applied to a different tube under test, attempts to establish absolute measures of the bore radius were not undertaken but only precise relative changes in radial distances were sought.

The mean and standard deviation of the data were calculated and are summarized in Tables I and II. The mean represents the average distance that the rifling seats from the gage. The value of the mean is used as a baseline from which all subsequent measurements are referenced. One should observe that while the gage is not measuring absolute radial distances it provides a means of measuring changes in radial distances. This is the advantage of this instrument over other devices, such as star gages, which can only provide diametrical data. The standard deviation of the data is an indication of the accuracy of the measurement. It should be noted that the standard deviations are highest on two riflings which are diametrically opposite and lowest on the two riflings which are 90° displaced from the maxima. This suggests that the gage consistently seats tightly along one particular axis of the tube. Additionally the repeatability of the gage readings depended upon the consistency of the seating.

The utility of the gage depends upon the degree of success in reducing statistical error. A confidence interval about the mean may be calculated using the Student T distribution: confidence interval is given by

$$\bar{x} - \frac{t_{\alpha/2}S}{\sqrt{N}} < \mu < \bar{x} + \frac{t_{\alpha/2}S}{\sqrt{N}} \tag{1}$$

where $\bar{x}$ = sample mean

$t_{\alpha/2}$ = T Score at $(1-\alpha)$ 100% confidence

S = standard deviation of the data

N = number of data points

μ = actual mean

Using rifling 10 of the land measurement and worst case standard deviation of 7.8 and a 90% confidence interval

$$260.2 - \frac{1.796 \times 7.8}{\sqrt{12}} < \mu < 260.2 + \frac{1.796 \times 7.8}{\sqrt{12}}$$

$$256.1 < \mu < 264.2$$

the actual mean lies between 25.6 and 26.4 mils.

If it is required to reduce the size of this interval in order to obtain more accurate results equation (1) can be used. Notice that an increase in the number of data points will decrease the interval size. Thus, from equation (1) for a given tolerance of error, the number of data points necessary to obtain this confidence level may be calculated

$$N = \left(\frac{Z_{\alpha/2}\sigma}{e}\right)^2 \qquad (2)$$

where e = maximum error in mils

$Z_{\alpha/2}$ = Z score at $(1-\alpha)$ 100% confidence

σ = standard deviation*

N = number of necessary data points

*The standard deviation σ is estimated by taking a preliminary sample size $N \geq 30$.

Assuming an error tolerance of ± 0.5 mils, a standard deviation of 0.8 mils and a 95% confidence level:

$$N = \left(\frac{1.96 \times 0.8}{0.5}\right)^2 = 9.8 \cong 10$$

Approximately 10 data points would be necessary.

The bore erosion gage can provide accurate changes of the dimensions of the bore radius. Virtually any level of statistical accuracy may be realized by adjusting the number of data points. The limitations of the gage's accuracy are its electrical and mechanical tolerances which are adequately described in reference 1.

In the second test, the electropolishing of a gun tube was investigated. Prior to electropolishing, ten profile runs were obtained and rifling means and standard deviations were calculated. A summary of the results appears in Table II. After electropolishing for one hour, three profiles were obtained.

The initial ten profiles show that rifling numbers 6 and 19 have the lowest standard deviations. Subtracting the new means from the original means for these two riflings yields a change of 5.1 and 4.9 mils respectively. After a second electropolishing step of the tube, five profiles were recorded, and the difference between the two means calculated. The result was a difference of 15.2 mils from the original tube radius, which suggests a removal of 10 mils off the radius during the second electropolishing step.

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[1] S. J. Krupski and F. J. Audino, "Measurement of Bore Erosion," WTV-QA-7701, December 1977.

These results are consistent with the polishing durations; when polishing time was doubled so did the amount of material removed, and the values compare remarkably well with the results of a star gage (three point) and an in-process ultrasonic system which monitored the polishing process.

CONCLUSION

Several independent tests which have been presented confirm that the bore erosion gage has been successfully modified and can be used effectively to measure relative changes of the bore radius. These measurements are accurate and easily reproduced.

The problems associated with the calibration of the gage for monitoring the absolute bore radius are numerous; the calibration is very time consuming and therefore not likely to be practical for this application.

The modified gage will be put to service in the measurement of the thickness and concentricity of chrome and other protective coatings of 105 mm M68 tubes. These materials are presently being evaluated for their potential use in solving the secondary wear and erosion problem.

REFERENCES

1. S. J. Krupski and F. J. Audino, "Measurement of Bore Erosion," WTV-QA-7701, December 1977.

TABLE IA. SUMMARY OF RADIAL GROOVE MEASUREMENTS (1×10^{-4} in) OF NON ERODED TUBE

Run #	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x}$	s
Rifling #														
1	707	714	713	719	717	708	710	707	711	708	712	708	711.2	4.0
2	727	733	734	735	735	728	730	727	730	729	731	727	730.5	3.1
3	730	746	746	746	745	742	742	740	742	741	741	742	741.9	4.4
4	745	754	753	753	753	752	753	748	748	750	750	751	750.8	2.8
5	752	757	753	754	756	757	757	752	751	753	763	756	755.1	3.4
6	749	754	749	750	751	754	753	750	747	750	748	752	750.6	2.3
7	741	743	740	738	740	749	746	743	737	741	739	744	741.8	3.5
8	728	731	726	723	727	737	733	733	723	730	726	732	729.1	4.4
9	710	712	707	703	707	718	714	714	703	710	706	712	709.7	4.7
10	675	688	682	680	681	697	691	688	680	685	680	690	684.8	6.2
11	659	660	658	654	655	670	664	663	653	661	655	663	659.6	5.0
12	630	630	628	626	627	640	633	633	624	630	624	633	629.8	4.6
13	598	599	599	595	599	609	603	604	594	600	596	603	599.9	4.3
14	572	573	568	569	570	580	576	576	567	573	568	575	572.3	4.2
15	546	546	544	544	545	553	550	548	543	550	543	548	546.7	3.2
16	523	523	523	521	523	530	527	525	521	524	522	526	524.0	2.7

(CONTINUED)

TABLE IA. SUMMARY OF RADIAL GROOVE MEASUREMENTS ($1x10^{-4}$in) OF NON ERODED TUBE (CONT'D)

Run #	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x}$	s
Rifling #														
17	507	508	509	503	508	512	511	510	507	510	507	511	508.6	2.5
18	498	498	500	498	500	501	498	500	499	499	498	499	499.0	1.1
19	493	495	496	497	498	495	494	495	498	494	494	495	495.3	1.7
20	498	497	501	503	503	496	500	500	503	499	501	498	499.9	2.4
21	507	511	513	516	516	504	507	508	514	509	512	508	510.4	3.9
22	525	527	531	535	534	520	525	525	533	526	530	528	528.0	4.6
23	545	551	552	559	556	542	547	547	554	548	551	547	549.9	4.9
24	572	577	580	586	582	567	573	573	581	573	577	573	576.2	5.3
25	601	604	607	613	613	594	601	603	610	600	606	597	604.1	6.0
26	630	634	637	644	642	613	631	630	637	630	633	632	632.8	7.8
27	659	663	665	671	660	654	660	660	667	659	662	659	661.6	4.5
28	682	693	696	698	694	680	689	686	691	688	691	684	689.5	5.6

TABLE IB. SUMMARY OF LAND RADIAL MEASUREMENTS ($1x10^{-4}$in) OF NON ERODED TUBE

Run #	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x}$	s
Rifling #														
1	213	215	219	212	218	210	203	214	218	215	218	217	214.3	4.6
2	237	242	243	245	244	235	240	239	244	240	245	241	241.3	3.4
3	260	263	265	266	265	259	260	262	263	262	266	261	262.7	2.5
4	273	280	280	280	280	277	280	279	278	280	281	282	279.2	2.4
5	290	293	290	291	291	291	293	289	290	291	292	293	291.2	1.4
6	297	298	296	296	296	300	300	300	297	300	298	302	298.4	2.0
7	298	299	293	294	294	302	300	300	295	300	297	303	297.9	3.4
8	292	292	286	286	287	297	294	295	288	294	290	297	291.5	4.1
9	277	277	273	270	273	285	280	282	273	280	275	288	277.4	4.7
10	262	260	254	254	254	267	264	265	256	263	257	266	260.2	5.0
11	239	238	231	230	233	247	242	243	234	240	235	243	237.9	5.4
12	213	210	205	205	206	220	215	217	207	215	208	217	211.9	5.8
13	182	182	187	176	187	190	185	187	178	185	180	188	183.9	4.3
14	156	253	148	148	148	160	157	157	150	157	151	158	153.6	4.5
15	126	125	122	120	121	131	128	129	122	129	125	128	125.5	3.6
16	100	97	96	95	96	104	102	101	98	103	99	103	99.5	3.2

CONTINUED

TABLE IB. SUMMARY OF LAND RADIAL MEASUREMENTS ($1x10^{-4}$in) OF NON ERODED TUBE (CONT'D)

Run #	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x}$	s
Rifling #														
17	78	76	74	75	76	80	78	79	78	80	78	80	77.7	2.0
18	60	58	57	59	59	62	61	61	62	61	62	63	60.4	1.9
19	48	47	48	49	49	47	48	49	52	50	50	50	49.9	1.5
20	43	42	44	46	45	40	43	43	47	46	47	43	44.1	2.2
21	43	43	46	48	47	40	43	43	50	47	48	44	45.2	2.9
22	49	50	53	56	57	46	50	50	58	54	56	50	52.4	3.8
23	59	65	67	70	70	57	64	63	73	66	69	64	65.6	4.7
24	79	84	87	90	88	76	81	80	90	83	87	80	83.8	4.7
25	101	106	108	113	113	98	104	103	114	106	109	104	106.6	5.0
26	126	130	131	136	137	122	130	127	138	130	135	130	131.0	4.8
27	155	159	163	167	163	150	157	155	166	158	164	157	159.5	5.2
28	183	188	188	195	191	178	185	183	194	187	192	186	187.5	5.0

TABLE IIA. SUMMARY OF GROOVE RADIAL DATA (1×10^{-4} in) FROM OLD TUBE PRIOR TO ELECTROPOLISHING

Run #	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	s
Rifling #												
1	507	506	508	503	506	494	495	510	501	498	502.8	5.6
2	500	498	500	497	499	489	490	502	493	490	495.8	4.9
3	493	491	496	490	491	483	485	494	489	488	490.0	4.0
4	489	488	490	485	487	482	482	489	483	486	486.1	3.0
5	487	487	486	484	483	483	483	483	482	485	484.3	1.8
6	485	484	485	485	485	486	487	486	484	489	485.6	1.5
7	487	488	489	489	488	492	492	487	487	493	489.2	2.3
8	492	492	494	495	491	499	499	491	492	499	494.4	3.4
9	497	499	500	500	498	506	508	495	500	507	501.0	4.5
10	503	506	505	509	505	503	506	501	508	514	508.0	5.0
11	511	514	513	517	514	522	526	507	517	523	516.4	5.9
12	520	522	522	527	523	531	533	514	523	533	524.8	6.1
13	529	532	530	534	532	542	542	523	534	542	534.0	6.3
14	538	540	537	541	540	549	549	532	542	549	541.7	5.7
15	544	548	545	549	549	553	555	541	549	554	546.7	4.5
16	552	551	552	554	556	561	559	549	555	561	555.3	4.0

CONTINUED

TABLE IIA. SUMMARY OF GROOVE RADIAL DATA (1×10^{-4} in) FROM OLD TUBE PRIOR TO ELECTROPOLISHING (CONT'D)

Run #	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	s
Rifling #												
17	557	558	556	559	559	562	563	554	559	562	558.9	2.9
18	563	562	559	562	560	562	562	559	562	564	561.5	1.7
19	561	561	558	561	561	561	562	561	563	563	561.2	1.4
20	562	562	559	562	562	559	559	562	561	557	560.5	1.8
21	561	560	560	560	550	556	552	561	559	556	558.4	2.9
22	559	555	558	556	556	549	549	558	555	548	554.3	4.1
23	552	549	551	549	549	542	541	557	549	546	548.5	4.7
24	549	544	544	543	543	533	532	549	542	534	541.3	6.2
25	542	538	539	537	537	527	526	541	533	528	534.5	5.9
26	533	532	532	525	528	521	515	538	524	517	526.5	7.4
27	524	524	523	517	519	510	509	527	517	511	518.1	6.5
28	516	514	514	509	511	502	499	518	508	502	509.3	6.5

TABLE IIB. SUMMARY OF LAND RADIAL DATA (1×10^{-4} in) FROM OLD TUBE PRIOR TO ELECTROPOLISHING

Run #	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	s
Rifling #												
1	89	88	91	88	89	79	80	93	85	81	86.3	4.8
2	77	78	82	78	79	70	70	81	73	70	75.8	4.7
3	66	68	71	68	69	61	61	70	63	61	65.8	4.0
4	55	57	60	56	50	52	52	57	52	52	55.1	3.0
5	43	46	49	45	47	44	44	45	42	45	45.0	2.0
6	32	37	38	37	37	38	37	34	33	38	36.1	2.2
7	23	30	30	30	30	32	33	26	28	32	29.4	3.0
8	18	23	24	25	24	28	30	20	23	30	24.5	4.0
9	15	20	20	21	21	28	28	14	20	28	21.5	5.1
10	12	17	18	20	19	26	27	11	18	27	19.5	5.7
11	11	18	18	20	19	28	28	11	19	28	20.0	6.4
12	13	20	20	21	21	30	31	12	21	30	21.9	6.7
13	19	24	22	28	25	35	35	17	28	34	26.7	6.5
14	26	31	30	33	31	41	41	23	32	41	32.9	6.3
15	34	37	38	41	39	48	48	31	41	49	40.6	6.1
16	43	48	48	50	49	56	55	41	51	56	49.7	5.1

CONTINUED

TABLE IIB. SUMMARY OF LAND RADIAL DATA (1×10^{-4} in) FROM OLD TUBE PRIOR TO ELECTROPOLISHING (CONT'D)

Run #	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	s
Rifling #												
17	55	59	58	61	59	64	63	52	61	65	59.7	4.0
18	67	70	68	72	69	73	71	65	71	72	69.8	2.5
19	77	80	79	81	80	81	80	77	80	81	79.6	1.5
20	88	90	88	90	90	88	88	89	90	88	88.9	1.0
21	98	98	99	99	97	95	93	99	99	95	97.2	2.5
22	101	107	106	105	105	101	99	107	106	100	104.2	3.0
23	111	112	111	110	111	103	101	112	108	102	108.1	4.4
24	114	113	114	112	112	103	101	117	111	103	110.0	5.6
25	113	113	113	111	112	102	100	118	110	102	109.4	6.0
26	111	111	112	108	109	100	97	113	105	98	106.4	6.0
27	108	108	108	102	104	96	93	109	101	95	102.4	6.0
28	100	100	101	94	98	88	86	101	91	86	94.5	6.3

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